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THE PERKIN-ELMER CORPORATION
(Report No. 8011)

Absorption of Light in Gases

First Semiannual Technical Summary Report
through March 31, 1965

Submitted by

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to the

OFFICE OF NAVAL RESEARCH

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The Perkin-Elmer Corporation
Electro-Optical Division

Report No. 8011

THE PERKIN-ELMER CORPORATION
E-O RESEARCH DEPARTMENT

Absorption of Light in Gases

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through March 31, 1965

Background and Objective

Our goal in this work is to study, optimize, and experimentally demonstrate acoustic detection of absorption of laser beams in gases. The outcome of the work will be a critical evaluation of the technique to determine whether it is suitable for a survey of extremely weak absorptions in the atmosphere, and as a sampling method for detection of trace constituents. We expect that in the course of the work, quantitative measurements in at least one laser wavelength region for air and some test gases will also be made.

Overall Plan

Apparatus for generating, detecting, and measuring acoustic pulses from absorbed laser light in gases is being designed, constructed, and calibrated. The overall equipment layout as we are planning it is shown in Figure 1. The pulsed laser fires through a gas sample contained in the acoustic chamber. Laser wavelength is varied by cooling the pulsed laser with the temperature control system. An energy monitor system records the relative energy of each laser burst.

Light absorption causes the gas in the laser beam to expand suddenly. The resulting sound wave is captured by the parabolic cylindrical reflector and focused by the parabaloidal reflector onto the microphone diaphragm. See Figure 2 for a back view of the acoustic chamber.

The diaphragm is a thin collodion membrane supported by a spider frame. It forms one end of the optical resonator associated with the single mode gas laser. See Figure 3 for details of the resonator. As in Figure 4, vibrations of the membrane in response to the acoustic pulses cause the resonant beam of the laser to shift position on the nose of the sensing prism. The resulting signal imbalance from the photodetectors is amplified and displayed on the oscilloscope for photographically recording the amplitude of the acoustic pulse. The imbalance or difference signal is also fed back to piezoelectric drivers on the gas laser's resonant mirror for maintaining single mode operation.

Calibration equipment for recording the pulsed laser wavelength is shown to the right in Figure 1 and in more detail in Figure 5. The grating and etalon together provide high resolution, and the hollow cathode lamp gives a stable wavelength reference.

The acoustic calibrator is not shown in the overall layout. It is a cylindrical device for generating acoustic pulses of known amplitude in the pulsed laser beam path. This is necessary for making quantitative measurements.

Design of Acoustic System

We studied the factors bearing on the efficiency and signal to noise of the acoustic focusing system. The laser beam diameter sets the sound's average wavelength. This was chosen as 2 mm, as a compromise between greater efficiency of conversion for small beams and greater absorption coefficient for the propagated sound for short acoustic wavelengths.

The maximum sound frequencies present will be about 3×10^5 cycles/sec. Here air attenuates at 12 db/meter. Thus, a short acoustic path is essential. A "clamshell" arrangement was chosen with an aperture of 30 cm. The total air path is 50 cm, giving attenuation of 6 db at the highest frequencies.

Since the sound mirrors have a figure tolerance of the order of the shortest sound wavelength they are made of aluminum. Cams for controlling the machining are being designed in the Perkin-Elmer Scientific Computer Facility.

Optical-Thermal Relaxation Time

Since it is essential that the absorbed energy be released as heat in a time short compared to the transit time of sound across the beam, (which is less than 3 microseconds), we had some concern about the speed of the thermal relaxation process, as it is known that slow relaxations are a cause of anomalous acoustic attenuation. Study indicates that for the optical energy levels we excite, the relaxation will be extremely fast, usually less than 10^8 seconds at 1 atmospheric pressure. It will be comparable to the lifetime associated with the pressure broadened linewidth of the optical bands observed.

Acoustic Detection System

The problem of building a microphone capable of reaching the Brownian noise limit at 100 to 300 kc requires a highly unconventional solution. First, in order to match the acoustic impedance of a transducer to the air so that acoustic noise energy will be freely transferred, we require a compliant diaphragm or ribbon so thin that it weighs less per unit area than a slab of air that is 1/10 of a sound wavelength in thickness. Acoustic waves of the Brownian noise pressure will then make this membrane move a few angstroms, or less than 1/1000 wavelength of light.

We will solve the problem by using a membrane mirror of the order of 1000 Angstroms thick as in a Golay infrared detector. Its motion will be measured by making it one reflector in an optical resonator illuminated by a frequency stabilized CW neon helium laser. (See Figure 3).

The frequency control system will keep the laser tuned to one mode of the mirror-membrane resonant cavity. Acoustic pulses will detune the resonator faster than the laser frequency control loop can follow. The acoustic signals will therefore be seen on the error signal of the frequency control loop. (See Figure 4).

The frequency controlled laser, a new single-mode unit designed on another project for very good short term stability and tight servo control, is almost complete.

Absorption Sensitivity

We reviewed the calculations of absorption sensitivity to determine a reasonable goal in this first experiment. The gas sample will be outside the pulsed laser resonant cavity for simplicity. Also, the laser output power will be reduced somewhat by cooling. For a 0.05 joule pulse and a 2 mm diameter beam, it should be possible to measure absorptivities as small as 10^{-6} cm^{-1}, when the limiting noise is due to Brownian motion of the air. Measuring an absorptivity as small as 10^{-6} cm^{-1} will be a significant demonstration of the usefulness of the method, and probably will not require elaborate refinements.

Absolute Acoustic Calibration

Several methods of calibrating the acoustic chamber and detector have been conceived and studied. The plan is to generate a cylindrical acoustic pulse of known amplitude in the acoustic chamber by some device or physical process. We have estimated the performance of an electrically pulsed hot wire stretched in the laser beam path. We have also considered an electromagnetically expanded tube. The final method has not been chosen yet.

Pulsed Laser Construction

Design and construction of the pulsed laser has been deferred temporarily, because current research on another project at Perkin-Elmer on single mode lasers using cryptocyanine dyes appears to be very promising for this experiment. When this method of making single mode pulses has been thoroughly worked out on the other project, we will build a breadboard temperature scannable single mode laser for this project.

First Measurements

Some data on the fine structure of atmospheric attenuation is now available. In the wavelength region between 6941Å and 6943Å there are several weak absorptions, as shown in Figure 6. This region may be scanned by cooling the laser from 300°K down to 250°K approximately. We are planning to measure atmospheric absorptivity here as a first experiment. It will be necessary to measure the wavelength of each laser pulse with a resolution of 133. An etalon and grating have been chosen to do this. The etalon will provide resolving power, and the grating will separate the orders. A wavelength reference lamp has also been chosen for absolute calibration.

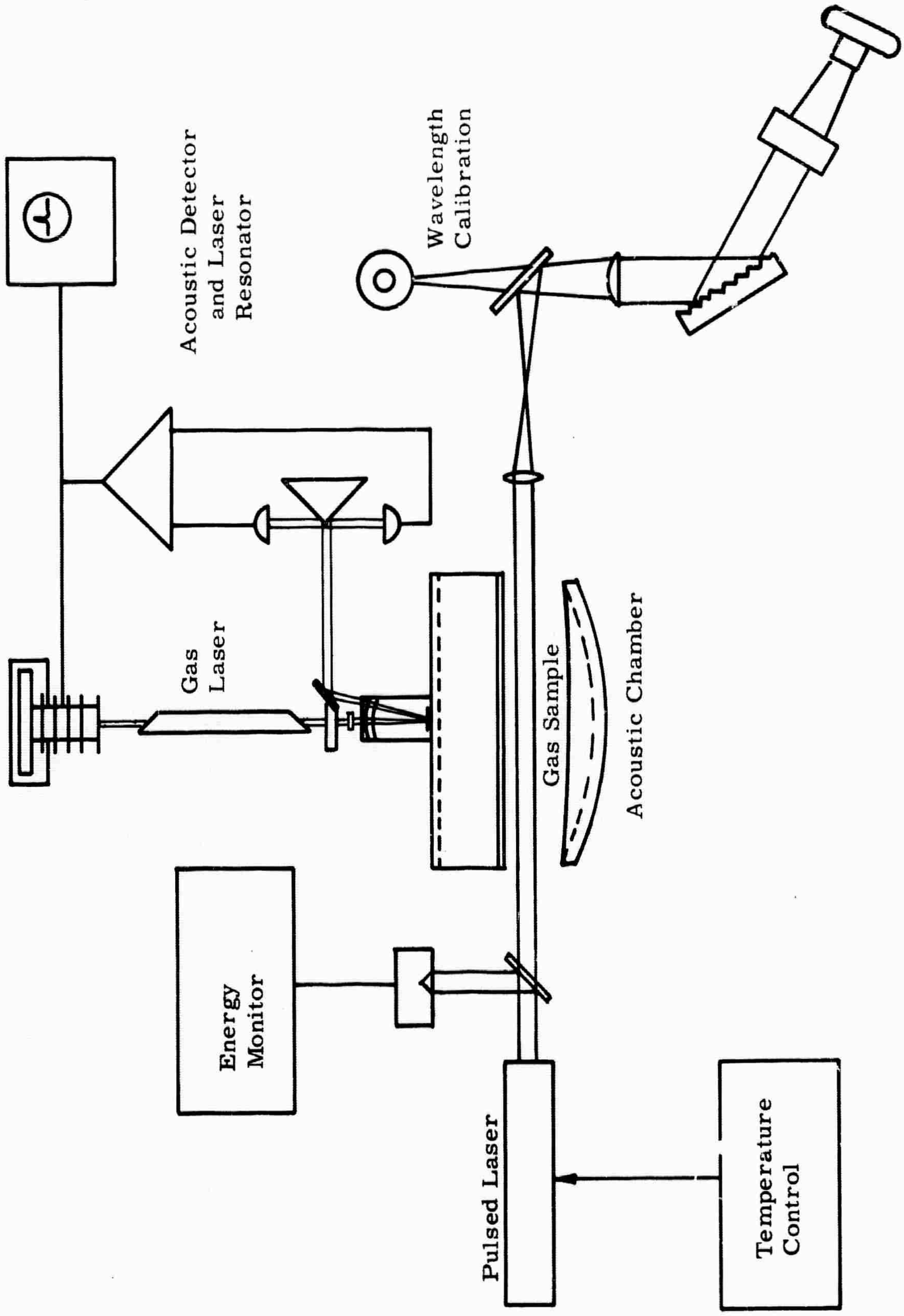

Figure 1. OVERALL LAYOUT

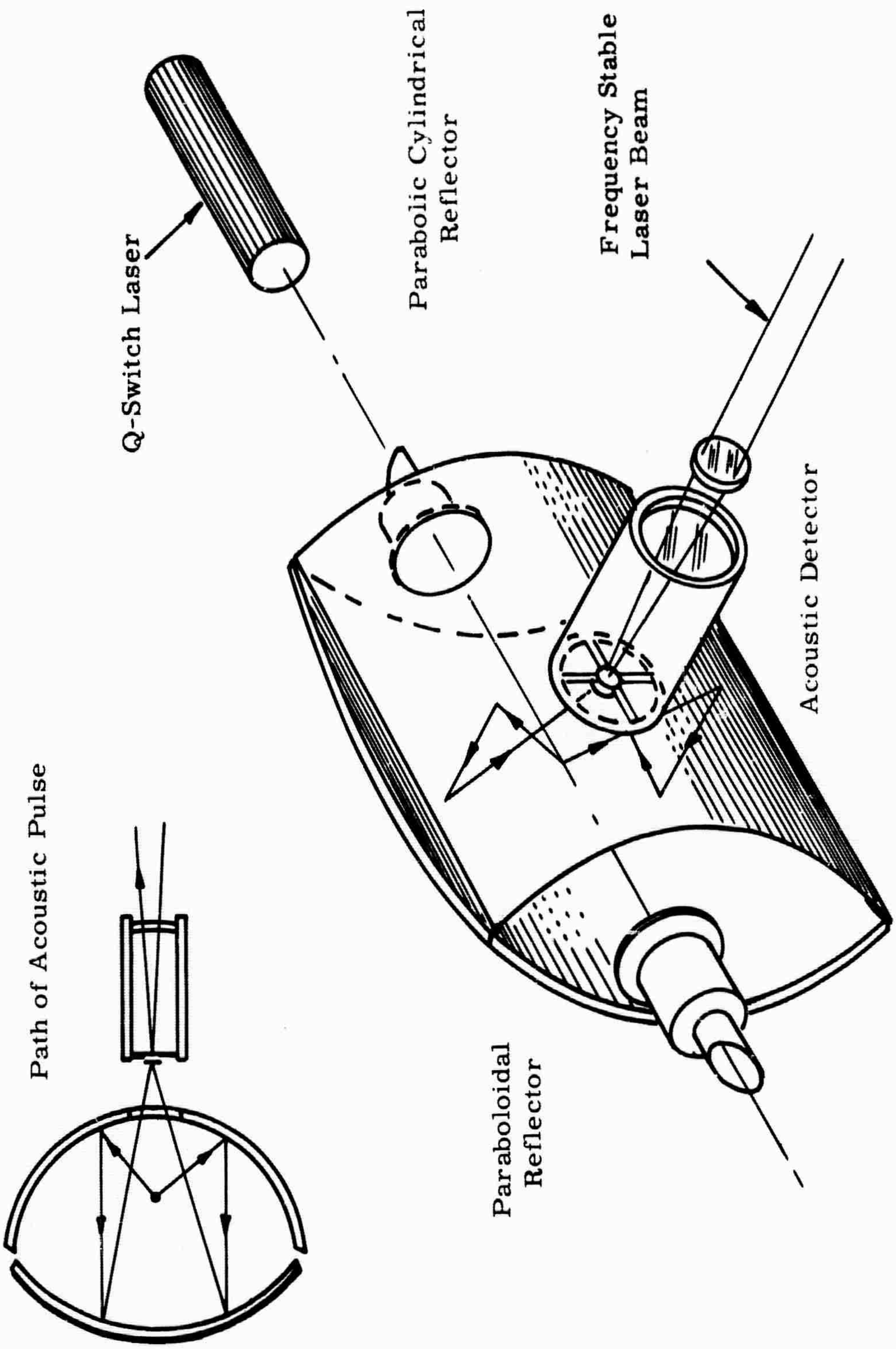

Figure 2. ACOUSTIC CHAMBER

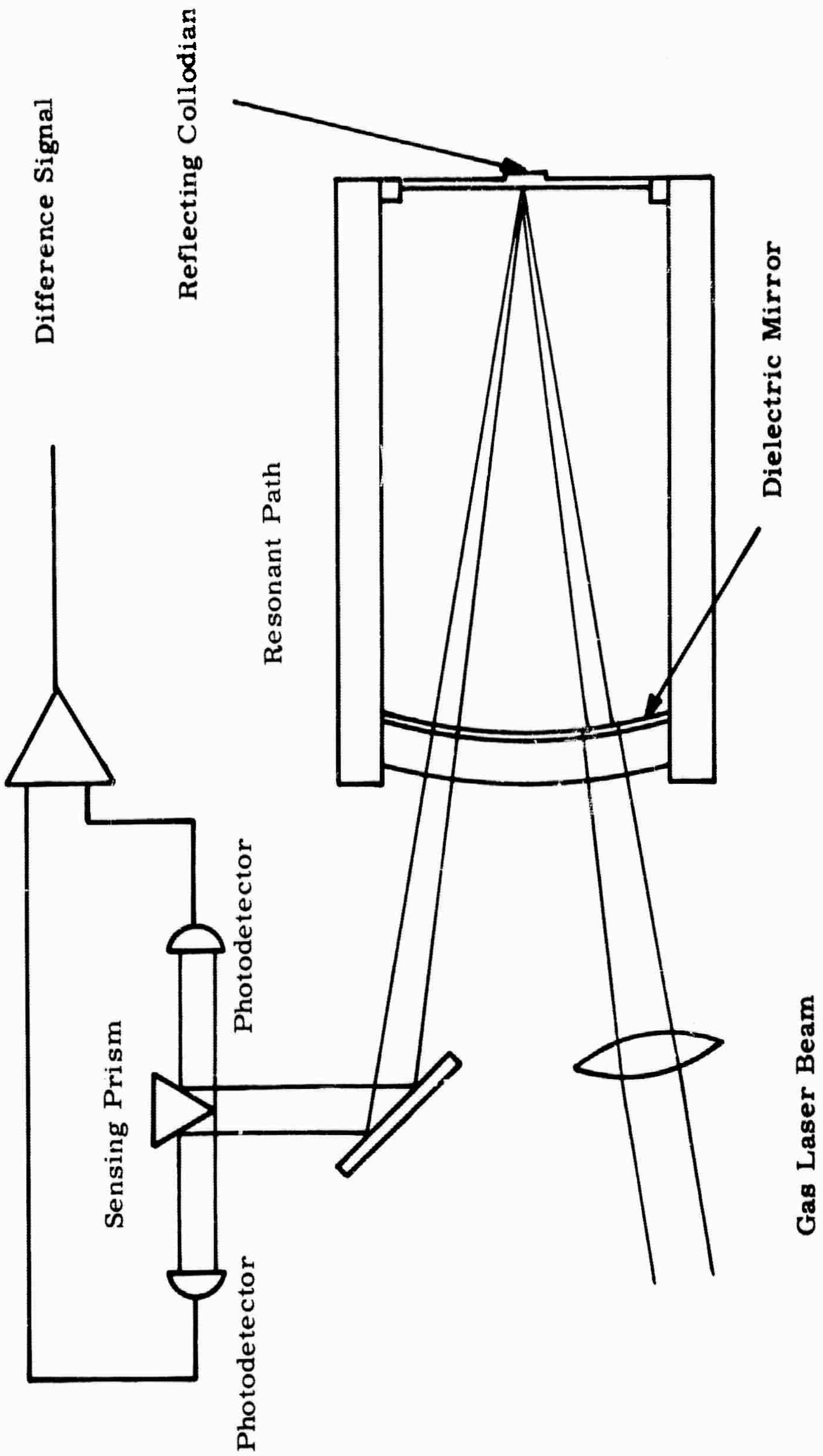

Figure 3. ACOUSTIC DETECTOR AND LASER RESONATOR

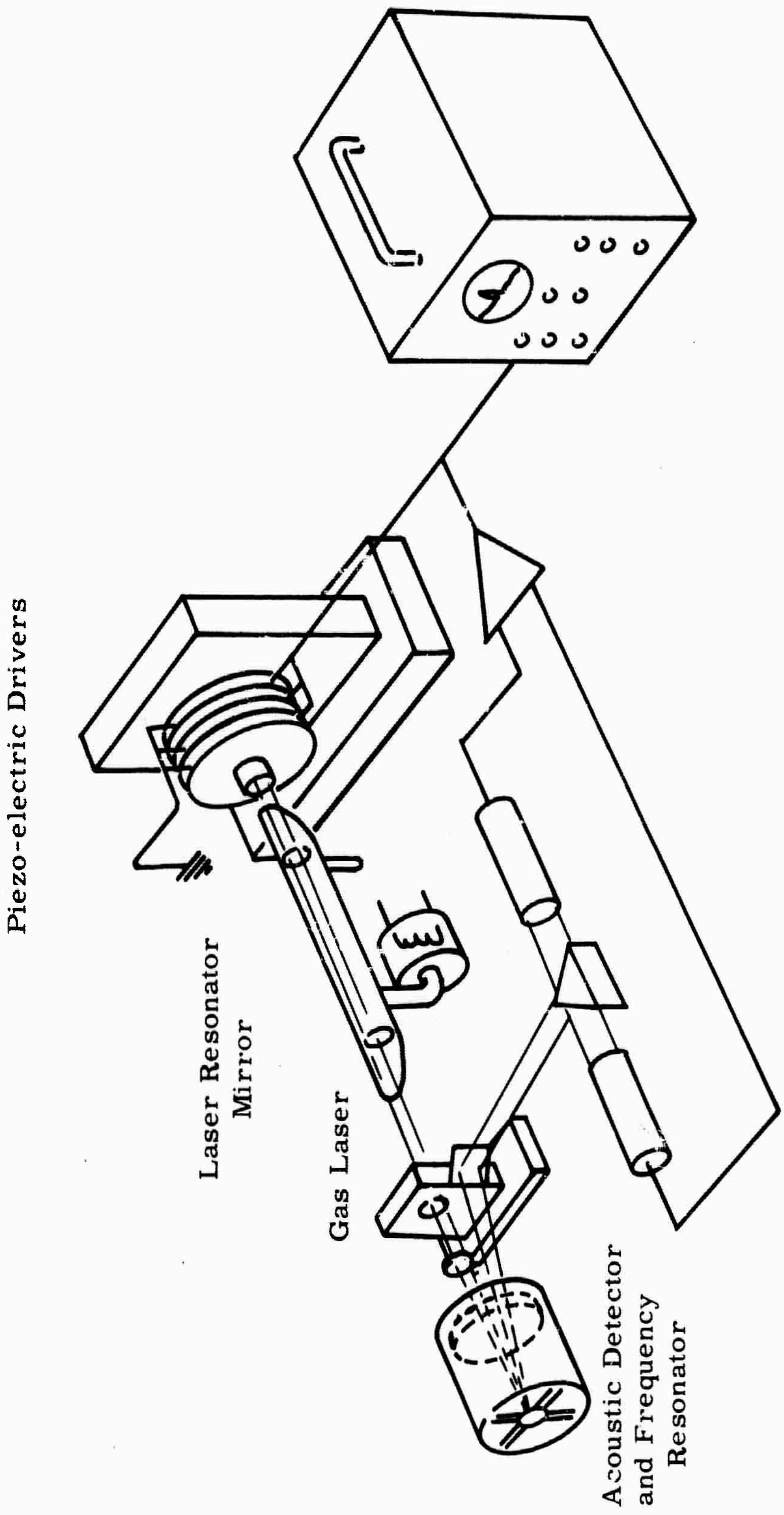

Figure 4.
DIAGRAM OF FREQUENCY STABILIZED LASER SYSTEM AND ACOUSTIC DETECTOR

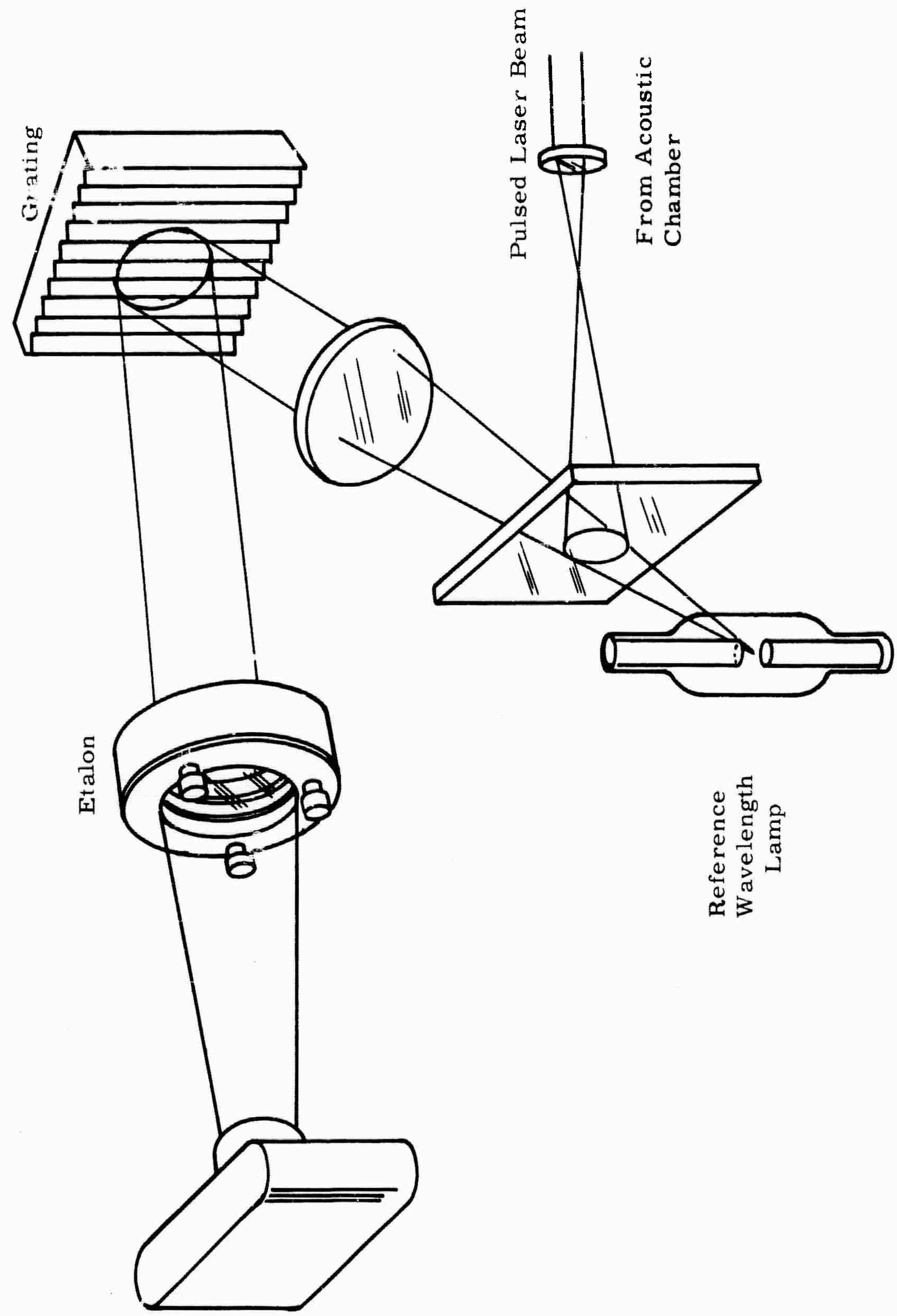

Figure 5. WAVELENGTH CALIBRATION

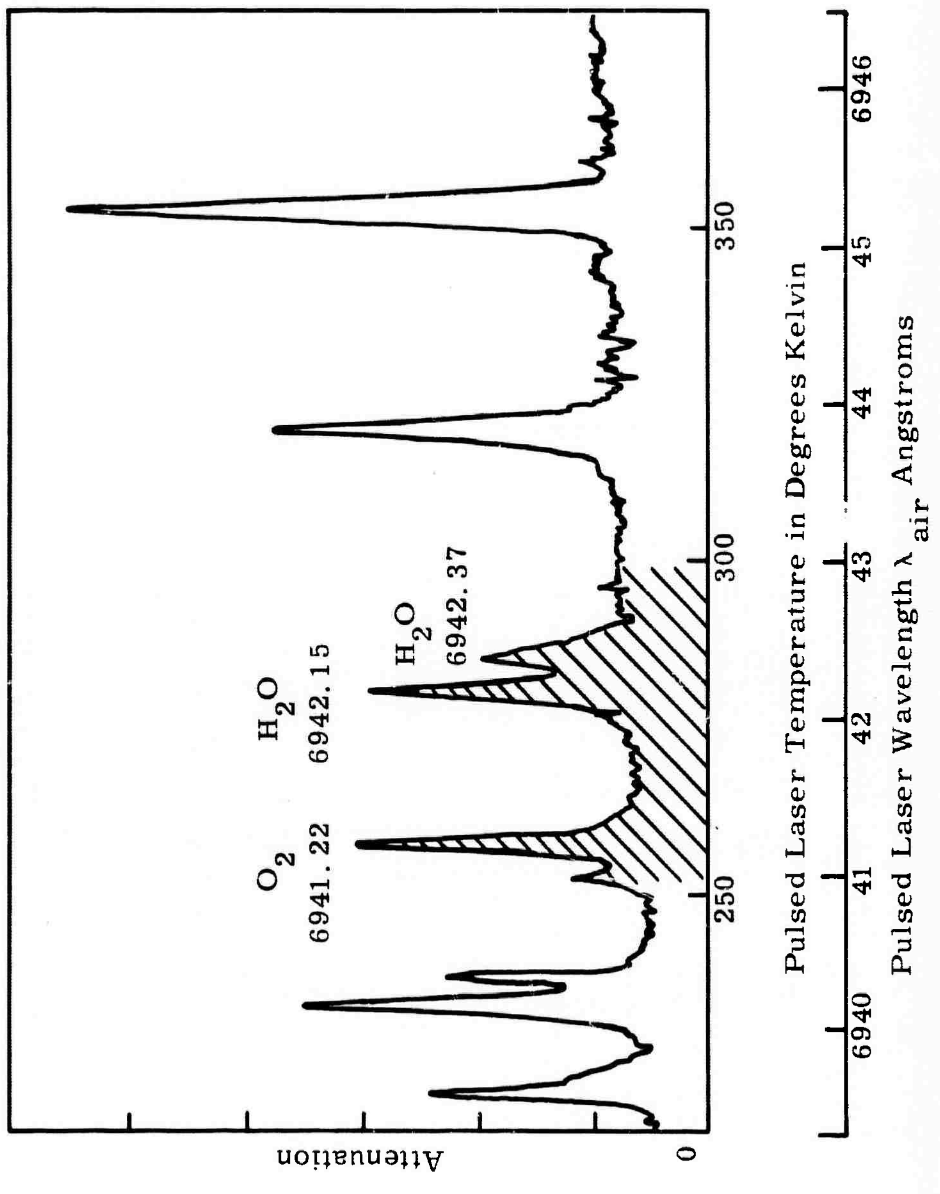

Figure 6. ATMOSPHERE ATTENUATION

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13. ABSTRACT

Evaluation of a method for measuring molecular absorptivities as small as $10^{-6}cm^{-1}$ is being conducted. Sound pulses generated by the absorption of ruby laser light are to be focused on a collodian membrane microphone: Membrane motion of as little as 5Å will be detected by making the membrane one reflector of an optical resonator illuminated by a frequency stabilized CW helium-neon laser. Signals will be observed in the frequency control loop. Wavelength scanning of the ruby laser will be done by temperature control over a 2Å region. Optical-thermal relaxation times have been studied. They are less than 10^{-8} seconds, too short to disturb the acoustic pulse. Ruby laser wavelength will be calibrated with a wavelength reference lamp, an etalon, and a grating, to provide resolving power.

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Weak absorption of light Pulsed laser applications CW laser applications Acoustic detectors Molecular absorption						

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